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Human-Systems Integration (HSI) and the Network Integration Evaluations (NIEs), Part 3: Mitigating Cognitive Load in Network-Enabled Mission Command

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14. ABSTRACT
This report is the third in a series discussing Human-Systems Integration (HSI) within the context of the Network Integration Evaluations (NIEs). The focus of this report is concrete actions for mitigating cognitive load in network-enabled mission command. Cognitive load is defined as the aggregate mental load placed on battle-staff personnel by a complex mission command work setting. NIE results suggest there are 3 primary contributors to excessive cognitive load in NIE command posts: 1) component ergonomics, 2) integration deficiencies, and 3) training. These factors combine and act to increase the aggregate level of perceived complexity and cognitive load for the battle staff. The mission command role is intrinsically complex and demanding. However, a work setting with a large number of design-related “rough edges” along with integration problems will give the impression of being more complex and intimidating than one that has been better designed and integrated. While some of the cognitive load associated with mission command in NIE command posts is intrinsic to role, high levels of extraneous cognitive load are needless consequences of insufficient attention to HSI in component design and integration coupled with inadequate training for both individual system users and for battle staffs functioning as a team.

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1. Introduction

This report is the third in a series addressing Human-Systems Integration (HSI) support to US Army force modernization initiatives. HSI encompasses the technical domains of Human Factors Engineering (HFE), manpower, personnel, training, system safety, personnel survivability, and health hazards (Headquarters [AR 602-2.27] 2015). In broad terms, HSI focuses on Soldiers and their interaction with everything in the environment associated with military systems and organizations. Force modernization is an ongoing process involving the replacement of existing materiel and technologies with newer, potentially more-capable versions. The imperative for force modernization is the rapid pace of technological innovation coupled with the evolving complexity of threats facing the US military. Within the Army, a primary thrust of force modernization is the development of technologies and systems to support what is termed network-enabled operations. A cornerstone of network-enabled operations is the development and deployment of a robust supporting network. Network Integration Evaluations (NIEs) are a series of semiannual exercises intended to integrate and mature the Army's tactical network in an operational context. During an NIE the Army 1) conducts integrated and parallel operational tests of selected Army programs of record, 2) evaluates developmental and emerging network capabilities in an operational environment, and 3) assesses non-networked capabilities in an integrated operational environment.

The scope of the NIEs permits human performance effects and HSI issues to be assessed at the individual Soldier-machine level, as well as at the system-of-systems and unit levels. Human performance assessments at the work system level for functional teams and units is sometimes referred to as macroergonomics (Hendrick and Kleiner 2002). Macroergonomics is concerned with the analysis, design, and evaluations of work systems. As used here, a work system refers to a sociotechnical system consisting of both people and technology intended to accomplish a specific organizational function. Sociotechnical systems analysis is an approach to organizational work design and assessment that concerns the interaction of people and technology in operational work settings. Outside the NIEs, few other venues provide an opportunity to assess Soldier performance effects and issues at the sociotechnical systems level. The end result of these multilevel HSI assessments is to provide decision makers with findings and recommendations concerning the doctrine, organization, training, leadership and education, and personnel (DOTLP) modifications necessary to make effective use of the equipment and technologies underpinning network-enabled operations and other aspects of force modernization.

1.1 HSI within the NIE Context

For the past 4 years (2012–2016), the US Army Research Laboratory's (ARL) Human Research and Engineering Directorate (HRED) has provided HSI support to the Brigade Modernization Command (BMC) for the NIEs. ARL/HRED personnel have participated in the NIEs in 3 capacities. First, ARL/HRED personnel have provided HSI support to the Army Test and Evaluation Command during formal operational tests of individual equipment items. These operational tests are embedded within an NIE. Second, HRED personnel have provided limited, mostly laboratory-based HSI support for the evaluation of systems of systems used within the exercise. A system of systems is an assemblage of task-oriented systems that are integrated to create a new, more complex system that offers more functionality and performance than the simple sum of the component systems. A command post (CP) is a good example of such a system of systems. Third, ARL/HRED personnel from the Fort Bliss Field Element have provided direct support to the BMC for the evaluation of systems of systems used within an integrated operational environment. Historically, Army HSI has been applied at the individual system level for programs of record. HSI applied at the system-of-systems and unit levels is a relatively new undertaking. A large-scale exercise like the NIE permits macro-level HSI issues associated with systems of systems and units undergoing modernization to be assessed.

The ARL/HRED team's first look at the macro-level HSI issues was during NIE 13.1. After observing field operations and reviewing database entries during that exercise, ARL/HRED staff members concluded that the cognitive load associated with network-enabled mission command was emerging as a major HSI concern. The cognitive load associated with mission command performed using modernizing NIE CPs also was an expressed concern of the then Chief of Staff of the Army and other elements of the Department of the Army (DA) staff. Consequently, the primary focus of ARL/HRED's direct HSI support to the BMC during subsequent NIEs was mitigating the cognitive load associated with mission command as conducted in modernizing CPs. The term "modernizing" means that NIE CPs are an experimental work in progress using updated systems and technologies not yet available to most other Army units. In present usage, cognitive load is defined as the aggregate mental load placed on battle staff team members and other CP personnel by an increasingly complex mission command work setting. Battle staff is a nondoctrinal term that refers to the mission command personnel within a unit. The term typically is associated with staffs at the brigade and battalion levels. Battle staff members typically include the unit commander, the unit executive officer, the unit's principal staff officers, ad hoc staff such as the battle captain, battle noncommissioned officer (NCO), and operators for each of the mission command systems located in the CP.

The primary focus of the ARL/HRED's HSI support to BMC during NIE/Army Warfighting Assessment (AWA) 16.1 remained mitigating the complexity and cognitive load associated with network-enabled mission command. An AWA is a variant of the conventional NIE paradigm primarily concerned with identifying nonmateriel solutions to specified Army warfighting challenges. Nonmateriel refers to solutions involving changes in the DOTLP domains cited previously. For NIE/AWA 16.1, ARL/HRED's work was performed in support of the DA's Focused End State 3, Objective 3.5: Reduce overall network complexity. Based on results across previous NIEs, the ARL/HRED team had provided mitigation recommendations in 3 broad areas affecting CP and mission command complexity and associated cognitive load: 1) mission command systems integration, 2) Knowledge Management (KM), and 3) individual and battle staff team training. Mission command systems integration was further divided into interoperability effects and operational integration challenges. Operational integration refers to incorporating new materiel solutions into CP and mission command processes and procedures.

The team's mission command complexity-cognitive load work during NIE/AWA 16.1 was focused on validating and refining findings and recommendations from NIEs 13.1–15.2. Collectively, these recommendations are directed at mitigating the cognitive load associated with network-enabled mission command. In addition, the ARL/HRED support team's charter for NIE/AWA 16.1 was expanded to include network (i.e., Warfighter Information Network–Tactical, or WIN-T) and network operations complexity and the impact of that complexity on mission command capabilities and performance. The team's extension into network-related topics was an exploratory effort intended to set the stage for a more detailed assessment of emerging issues during subsequent NIEs. Consequently, the team's treatment of network complexity is cast solely in terms of observations with related discussion that can serve as a guide to follow-on analyses. Each of these topic areas is addressed separately in the analysis sections to follow.

1.2 Methodology

Data relevant to the previously mentioned topics were obtained from 1) field observations in CPs during NIE operations, 2) interviews with commanders, their senior staff, brigade- and battalion-level battle staff members, and discussions with network support personnel (e.g., unit S6 [Signal/Communications]) personnel and field service representatives [FSRs]), 3) discussions with supporting exercise observer/analysts, and 4) a review of NIE database entries. During field observations in CPs, ARL/HRED analysts were accompanied by a mission command subject matter expert (SME) provided by the Army Training and Doctrine Command's (TRADOC's) Mission Command Center of Excellence (MCCoE) at Fort Leavenworth, KS. This SME was an experienced military analyst familiar with CP operations, mission command procedures, the Military Decision Making Process (MDMP), and NIE equipment and objectives. He assisted ARL/HRED personnel in 1) gaining access to unit CPs, 2) making essential introductions to unit battle staff and network support personnel, 3) understanding what was transpiring as the mission command operations were observed, and 4) focusing follow-on interviews on key aspects of cognitive load in mission command and network/S6 operations. ARL/HRED personnel also used this SME after the fact to assist in making sense of and clarifying observations, conclusions, and recommendations. For NIE/AWA 16.1, the ARL team also was supported by WIN-T SMEs from the system's prime contractor, General Dynamics Mission Systems. WIN-T SMEs were a source of background information on the network and its capabilities, and also served as an interface between the ARL team and network FSRs supporting the exercise.

1.3 Cognitive Load and Mission Command

Simply stated, cognitive load is defined as the aggregate mental load placed on the battle staff or other CP personnel by an increasingly complex mission command work setting. From an HSI perspective, Cognitive Load Theory (CLT) can be used to support the development of work settings such as a CP that efficiently use people's limited cognitive processing capacity to support effective job performance. A central aspect of CLT is the notion that humans' working memory architecture and its limitations should be a major consideration when designing or evaluating a work setting (Plass et al. 2010).

CLT distinguishes between 2 types of cognitive load: intrinsic and extraneous. Intrinsic cognitive load is primarily determined by the nature of the job being performed. Intrinsic load is high when job performance requires a large number of interactions involving a number of cognitive components. Extraneous cognitive load is the additional load beyond the intrinsic level, primarily resulting from poorly designed or integrated components along with inadequate levels of job performer expertise. A high level of extraneous load is argued to interfere with effective job performance. Because intrinsic load and extraneous load are considered additive from an overall cognitive load perspective, it is important that the total cognitive load associated with a work setting such as a CP should not exceed demonstrated human or team capabilities. It should also be noted that the cognitive load "drivers" most amendable to reduction or elimination fall into the extraneous load category. Good component design, appropriate component integration, and proper preparation of job incumbents are the keys to managing complexity and cognitive load in CPs supporting network-enabled mission command. As a construct impacting mission command performance, cognitive load is developed in additional detail in Hawley (2014).

ARL's HSI analysts identified 3 primary contributors to extraneous cognitive load in CPs as observed across NIEs.

Mission command system functionality and ergonomics. Many of the individual systems used to support mission command in NIE CPs are neither user friendly nor sufficiently reliable. Moreover, the components comprising the CP are developed and evaluated mostly in isolation and often by different proponents and vendors. Their relationship with other CP components is not always considered, and neither is their design based on an understanding of complex cognitive work in context. For purposes of the present discussion, the functionality and ergonomics of individual mission command systems were accepted mostly as "givens." ARL's HSI team did not extensively critique individual mission command systems in NIE CPs.

Mission command component integration. Many of the individual systems within CPs are not suitably integrated to support mission command as cognitive work. When used within the context of a discussion of complexity and cognitive load, the following 2 separate aspects of integration must be addressed.

Physical integration primarily refers to mission command component connectivity and interoperability. Do data flow as they should? Does this data flow facilitate effective information exchange across mission command systems? From a cognitive load perspective, the most important aspect of physical integration is component interoperability. Suitable component interoperability is one of the foundations of effective mission command.

Operational integration involves the incorporation of new mission command materiel solutions into battle staff processes and procedures. It has been observed that new technology often changes the nature of the work that that technology is intended to support. Operational integration is the organization's necessary response to such work changes. With respect to the current discussion, KM challenges are viewed as a separate but important aspect of operational integration. KM challenges are addressed in additional detail later in this report.

Effective physical and operational integration support users in making sense of information transmitted via technical connections, intuitively understanding the implications of that information, and responding appropriately. Effective component integration, interoperability, and information management are the foundations of suitable mission command performance.

Training and battle staff expertise. Many of the personnel using mission command systems have not been adequately trained on them individually or as an integrated equipment suite (i.e., as a system of systems). Moreover, battle staff personnel have not been provided sufficient on-the-job experience to become familiar with the equipment suites used to support mission command as an integrated warfighting function.

Detailed results addressing mission command complexity and associated cognitive load as observed across NIEs are provided in Hawley (2015).

2. Analysis Results, Part A: Mission Command Complexity–Cognitive Load

As noted in the previous section, ARL/HRED's HSI support team previously provided actionable mitigation recommendations in 3 areas affecting CP and mission command complexity and associated cognitive load: 1) mission command systems integration (discussed separately in terms of component interoperability and operational integration), 2) KM, and 3) individual and team battle staff training. In the present context, actionable means laying out specific actions that could be taken by a particular Army proponent to mitigate the issue at hand. These actions should also be practical and achievable within reasonable timeframes and available resource limits. The "challenges" directed at mitigating CP and mission command complexity and cognitive load cited previously serve to frame the findings, recommendations, and associated discussion in the sections to follow.

2.1 Physical Integration and Component Interoperability

As noted previously, interoperability refers to the network of sensor and communications capabilities that link users through various interfaces and enable them to acquire and share information. Component interoperability, the product of effective physical integration, is the foundation for effective mission command performance within a CP. Without effective transfer of information within and across CPs and component systems, mission command performance is impeded.

2.1.1 Finding

The developing mission command network being evaluated during the NIEs has been characterized by users as "complex and fragile" (Hawley 2015).

Interoperability of mission command component systems across the brigade remains unreliable and uncertain. This recurring unreliability interferes with smooth mission command operations within CPs and impedes horizontal and vertical integration across echelons. It also adds to the cognitive load imposed on elements of the battle staff. Battle staff personnel are required to continually "work the workarounds" to conduct mission command.

2.1.2 Recommendation

In the short to medium term, the primary means of dealing with interoperability challenges is to stress training and experience on the part of battle staff personnel. Observations across NIEs suggest that well-trained and experienced battle staff personnel are able to cope with and resolve many mission command problems attributable to interoperability shortcomings. The MCCoE's Mission Command Digital Master Gunner (DMG) course was found to be particularly useful in providing the necessary expertise in this area. In the long run, it is essential to emphasize smooth and seamless interoperability of mission command component systems. This is primarily an engineering and software development challenge. Part of the interoperability problem observed during the NIEs is the result of a lack of coordination across multiple vendors on aspects of design and component integration as basic as not having compatible software interface integration capabilities. Software and hardware developers often produce products without consideration of other systems that will be used as a suite, which makes it difficult for common analysis and collaboration across warfighting functions. Cognitive aspects of mission command system interoperability also must be addressed. The COE (Common Operating Environment) and CPCE (Command Post Computing Environment) represent potential solutions to mission command interoperability challenges in the mid to long term.

2.1.3 Discussion

Digital CPs can no longer be viewed as a collection of semi-independent systems that are cobbled together after the fact to support the mission command warfighting function. It is arguable that many of the interoperability problems in NIE CPs are attributable to the fact that component mission command systems are developed by separate program managers or vendors. These semi-independent systems are then physically integrated (i.e., wired together) to form a mission command system of systems. However, physical integration does not always result in sufficient levels of interoperability. Moreover, a cobbled together collection of mission command components is not necessarily a true system of systems when viewed from a cognitive performance perspective. The cobbled together nature of current mission command systems tends to result in compartmentalized analyses of data, thus making it difficult to transform that data into useful information. This compartmentalization also makes it difficult to share information across mission command systems and readily support battle staff processes and command decision making.

It is also important to bear in mind from the outset of development that a CP is a sociotechnical system. A sociotechnical system is one in which humans provide essential functionality related to deciding, planning, collaborating, and managing (Vicente 2006). It might be said that Soldiers and battle staff teams are the “glue” that sticks the overall system of systems together. It is thus necessary to consider the needs of the battle staff teams using mission command tools along with capabilities of the tools themselves (Wallace 2005). Viewing the CP as a sociotechnical system requires HSI concepts and practices to be applied from the outset of next-generation CP concept formulation and continue through development and testing. It is also necessary to apply HSI methods at the individual component, system-of-systems, and unit levels. It is also expected that new HSI issues will emerge when individual systems are integrated to form systems of systems, and still additional Soldier performance challenges emerge when systems of systems are embedded within in a unit context.

2.2 Operational Integration

Operational integration refers to integrating technical functions with the human cognitive processes they are intended to support and making that cognitive work more reliable. Practically speaking, operational integration involves incorporating new mission command materiel solutions into battle staff processes and procedures to increase their effectiveness and efficiency in execution. This is a necessary step in taking advantage of new digital technologies. The HSI team’s mission command SME noted that mission command processes and the MDMP have not changed much during the past 25 years. What has changed is the tool set used to support these activities. Achieving effective operational integration requires attention to the following: 1) the design of human interfaces, 2) CP procedures and workflow, 3) communication systems and practices, 4) battle staff training, 5) battle staff teamwork, and 6) CP organization and management. Effective operational integration supports users in making sense of information transmitted via technical connections, intuitively understanding the implications of that information, and responding appropriately.

It is interesting that in a case study of network-enabled operations in early Stryker brigades, Gonzales et al. (2005) commented on the need to restructure the MDMP itself to reflect new systems and capabilities. They observed (p. 110) that reengineering the MDMP "allowed the brigade to move from a traditional deliberate planning process to one that is highly adaptive and fully exploits the enhanced situational awareness and understanding. This is not an incremental improvement. Instead, we believe it reflects a quantum leap forward to a new type of planning and decision making strategy". These authors further remarked that the brigade had to deliberately focus on reengineering MDMP processes, procedures, training, and leadership thinking to make this enhanced planning capability a reality.

2.2.1 Finding

Battle staff battle drills and the MDMP are well documented. However, the operational integration of newer digital mission command systems into these processes is not well documented from an integrated system-of-systems perspective. The HSI team's mission command SME noted that tactical standard operating procedures (SOPs) are well laid out with manual processes but do not refer to the capabilities provided by the various mission command component systems. The SOPs have flow charts depicting the processes in the CP but do not show how tactical systems support those processes. The team's SME also noted that many of the unit's battle captains and supporting battle NCOs are inexperienced and have not been sufficiently trained in the use of mission command materiel systems; NCOs typically have not been to the battle staff course. Many of these personnel admit that they do not fully understand the capabilities of the various systems in the CP or how they are best used as a system of systems to support mission command as an integrated warfighting function.

2.2.2 Recommendation

TRADOC should use mission command SMEs and battle-lab-like resources to develop procedures and supporting publications that will serve as a "school solution" or "how to" guide for digital CP operations and network-enabled mission command. These procedures and supporting documents should outline validated best practices for using the mission command tools currently in the CPs. Moreover, procedures and documents should not be limited to program of record systems but rather should include all digital (e.g., SharePoint, Microsoft Office, and Google Earth) and analog tools used to support mission command. Guidelines for CP setup, physical organization, management, and tear down also should be provided. This set of products should not be singularly focused on commanders but rather should be structured to serve the entire battle staff. Procedures and supporting documents will need to be reassessed and revised as new or modified capabilities are added to CPs and as users gain field experience performing mission command using new tools. These products will also serve as the basis for integrated CP training.

2.2.3 Discussion

The recommendation in the previous section addresses 2 related issues. First, there are many ways of managing, integrating, and presenting information within a CP. This variability across units (some of which is necessary) increases the burden on incoming Soldiers to learn their gaining unit's systems, processes, and procedures. Excessive variability across units also limits the value of the experience these Soldiers bring from their former units. A common core of doctrinal and procedural standardization along with training based on this common core would ease this personnel transition process.

The second issue involves units developing SOPs and supporting documentation on their own. The HSI team has observed that such developments are occurring within the NIE test unit (2nd Brigade Combat Team [BCT], 1st Armored Division [2/1 AD]) and elsewhere across the Army in units receiving Capability Set equipment. This developmental activity is driven by necessity, and for the most part the HSI team views these actions positively. However, an associated danger is that the personnel developing these idiosyncratic products may not have a complete understanding of the various tools and capabilities available to them. They know only what they have experienced. Similarly, Soldiers have limited time in the field during an NIE and limited access to equipment during in the interim between NIEs. They thus have limited opportunity to reflect on procedural improvements or to assess potential alternatives. All of this can lead to nonoptimal solutions. Mission command SMEs with access to battle-lab-like facilities have the time to explore, test, and refine potential solutions. This is likely to lead to a more robust set of procedures and supporting documents than those developed by units operating on their own. The HSI team recognizes that different types of units with differing missions require the flexibility to tailor any such school solutions to their particular circumstances. However, a baseline school solution for network-enabled mission command might make unit tailoring processes faster and easier.

2.3 Knowledge Management

The Army defines KM as the "art of creating, organizing, applying, and transferring knowledge to facilitate situational understanding and decision-making" (Headquarters [FM 6-01.1] 2012). It also supports improved organizational learning, innovation, and performance. KM processes ensure that knowledge products and services are relevant, accurate, timely, and useable to commanders and decision-makers (Headquarters [FM 3-0] 2012). KM creates value for organizations by increasing operational effectiveness, decision quality, and unit innovation. A white paper on mission command training prepared by the MCCoE refers to KM as the "binding idea" in CP operations (MCCoE 2013). Following that notion, information is the “life blood” of network-enabled operations. The various systems supporting network-enabled mission command are there to provide the “right” information when and where it is needed. The essence of KM is comprehensive and efficient data and information management within and across CPs. In this sense, it should also be emphasized that effective KM involves more than the hardware and software used to facilitate data and information transfer. The human component of KM is essential to transforming information into usable knowledge.

2.3.1 Findings

Specific findings with respect to KM within the test brigade across recent NIEs are summarized as follows:

- The test brigade does not have a comprehensive KM program.
- The brigade’s KM officer (KMO) is not being used to support KM as an enabler for effective mission command.
- The unit lacks a comprehensive KM SOP and Annex Q of their Operations Order/Plan, the KM Annex.
- The brigade does not execute formal KM processes.
- What passes for KM in CPs is not standard across the unit’s echelons.
- Formal KM training has not been provided to personnel requiring KM skills.

2.3.2 Recommendations

The following recommendations are offered regarding KM based on the NIEs:

- The functions, activities, tasks, capabilities, and responsibilities associated with KM should be integrated into the Operations section (S3). This would foster the concept of a single information manager and authoritative source of guidance on KM across the unit’s echelons. The current Operations section would then control and manage all operational information along with those processes and products that contribute to it, and not just those aspects provided by battlefield automation programs of record.
- The brigade should work with the KM proponent at the MCCoE to develop and implement a baseline KM SOP and Annex Q. The format for Annex Q is provided in FM 6-0 (Headquarters 2014).

- The KM proponent at the MCCoE has developed and is prepared to present a 3-day KM Representative Course, which should be conducted for applicable unit personnel prior to a future NIE. KM training effectiveness and the impact of enhanced KM practices on mission command performance could be evaluated following the development of a KM SOP, supporting products, Annex Q, and suitable training for affected personnel.
- Consideration should be given to including KM skills in the Mission Command DMG course. This action would assist in bridging the tactical information management divide between the battle staff (battle captains and NCOs) and the KMO.

2.3.3 Discussion

KM deficiencies affecting mission command performance and contributing to cognitive load were first identified as issues during NIE 14.2. ARL/HRED's HSI support team followed up and confirmed those initial observations during NIE 15.1. During NIE 15.2, the team was joined by an SME from the KM proponent's office at MCCoE. The team's observations on KM deficiencies and their effect on mission command operations were once again confirmed. Potential paths forward for improving KM performance in CPs were identified. Results from NIE/AWA 16.1 validated these initial observations concerning KM deficiencies in the test brigade.

Contemporary CPs present an information-intensive performance setting for battle staff personnel across the brigade. Improved information management in CPs across the unit's echelons is critical to effective mission command. Failure to manage information effectively risks having much of the unit's critical data and information (data in context) effectively relegated to what has been termed an "information junkyard". Relevant information is "out there somewhere" but not readily accessible by the battle staff. Enhanced KM is thus a potentially fertile area for improving mission command operations as well as managing complexity and resulting cognitive load. To achieve this end, KM concepts and practices must be better integrated into the brigade's mission command operations at all echelons. This will require operational definition of KM doctrinal concepts as they apply to mission command followed by operational integration of KM procedures into CP and battle staff organization, mission command operational procedures, battle staff battle drills, and the MDMP. TRADOC must establish doctrinal standards for KM as part of mission command along with SOPs and templates for supporting KM products and tools. Use of the unit's formally trained KM personnel should be reviewed with an eye toward better employing those personnel to support CP practices and mission command operations. Formal KM-oriented training for the unit's mission command personnel is also necessary.

2.4 Individual and Team Battle Staff Training

The ARL/HRED HSI support team's reporting on NIE field operations has repeatedly emphasized the importance of training and follow-on experience to user perceptions of mission command complexity and cognitive load as well as success in using new materiel. Based on the team's experiences across 7 NIEs, it is arguable that the single largest contributor to perceived complexity and cognitive load during the NIEs is that the participants simply do not know how to use digital mission command systems individually and collectively. Moreover, users do not know how to function as a CP team (complex cognitive work is teamwork). There are obvious issues with mission command system interoperability and data flow within and across CPs, but it is not clear how much of that actually is attributable to lack of individual and team proficiency in using new mission command systems. Addressing training deficiencies for individuals and mission command teams is a critical aspect of cognitive load mitigation.

The following discussion of training-related findings and recommendations addresses 3 aspects of individual, team, and unit performance:

1) Preparation of individuals on the battle staff, along with orientation for commanders and senior staff

2) Unit collective training to reinforce individual task work skills and develop essential teamwork skills

3) Maintaining a core of unit battle staff expertise over time as personnel arrive at and depart the unit

Based on NIE observations and anecdotal reports, item no. 3 is an important aspect of unit performance at the intersection of unit training and local personnel management. It has been noted that the primary function of a peacetime military is maintaining readiness. The glue that holds materiel systems together and makes them more than a collection of hardware is Soldier expertise; however, there are high rates of personnel turnover in all military organizations. The human parts keep passing through the system, so to speak. Thus, even though a unit is combat-ready one day, it may not be combat ready the next day unless the expertise of the personnel departing is continually replaced by the newly acquired skills of those who have recently arrived. This high turnover rate of personnel and the need for continual replenishment of expertise is an important consideration in unit training planning and local personnel management. Maintaining essential levels of unit expertise cannot be left solely to the whims of the Army's formal personnel assignment system. Units must be proactive in managing available Soldier expertise, as with any other critical resource.

Specific training-related findings are reported as follows. Many of these findings are not unique to NIE/AWA 16.1 but have been observed across NIEs.

- Battle captains, chiefs of operations, current operations chiefs, and battle NCOs generally are not formally prepared for their positions and do not stay in those roles long enough to really learn their jobs. The mission-command-related issues that battle captains and NCOs must grasp are complex and require a high level of expertise (training followed by job-relevant practice with expert feedback) to meet the demanding pace of network-enabled operations. Few maneuver officer or NCO positions produce the skills needed for operating as part of a battle staff. Because the turnover rate for these positions is high, units are forced to send new officers and NCOs to be trained on the systems they are to use. In the case of officers, after they leave the operations sections they might not use those skills for a number of years. By that time, digital system skills will have decayed or changed to the point that extensive retraining is necessary. The norm for battle NCOs is that S2 is their terminal assignment.

- Much current digital systems training is excessively individual system focused (i.e., stove-piped) as opposed to being operationally oriented. For example, the Army does not need Command Post of the Future (CPOF, the primary mission command workstation) "operators" or, for that matter, operators of any of the other mission command systems in the CP. Rather, the Army requires battle staff personnel who do their jobs better because they know how to use CPOF and other mission command systems as supporting tools. It is necessary to guard against mission-command-related training being focused on using the tools of mission command rather than on learning to apply those tools to support the mission command warfighting function. The emphasis of mission-command-oriented training must be to enable the battle staff to assimilate the raw data that systems provide and transform that data into useful information that the commander can understand and use to make timely and relevant decisions.

- Training and experience are the 2 pillars of a highly functional battle staff. Currently, battle staff training is resource- and time-intensive to conduct. The test unit generally does not provide sufficient collective training to meld individuals into a competent battle staff. There is a considerable difference between a collection of individuals, no matter how well trained on individual systems they might be, and a competent battle staff functioning as in integrated team.

- The Mission Command DMG course offered at MCCoE was observed to produce both CPOF and mission command systems integration specialists. Battle staff personnel consistently commented on the positive impact of Mission Command DMGs on CP operations and mission command effectiveness.

- Maintaining a consistent level of battle staff expertise in units over time presents a challenge to unit leadership at all levels. As noted, much of the difficulty in maintaining consistent levels of battle staff expertise stems from the fact that none of the battle staff roles is a formal unit position. Current digital systems supporting network-enabled mission command require a higher level of expertise than older analog tools. Moreover, effective integration of mission command components is now a critical competency and should be reflected in guidelines for CP staffing.

2.5 Recommendations

Recommendations to mitigate the previous findings are provided as follows:

- The Army must more systematically prepare battle captains and other members of the battle staff for their roles. It is unreasonable to expect a pre-company-command battle captain to function effectively at the battalion or brigade level without extensive training and on-the-job mentoring. At a minimum, it would be useful to develop a checklist of what training or prerequisite experience is necessary to serve in various battle staff roles.

- The focus of digital systems training should be changed to be more operationally oriented rather than being system oriented. The focus must be how to use digital tools to support the mission command warfighting function as opposed to being focused solely on system operation (i.e., “buttonology”). Such training may start with system operation but it cannot stop there. Digital systems training must progress from individual, to crew, to integrated CP training. The Mission Command Digital Gunnery Tables concept developed by MCCoE, and currently being piloted in the 1st Infantry Division at Fort Riley, is potentially a good first step in developing integrated training for CP personnel functioning as a team.

- The Army must develop and deploy low-overhead, readily accessible collective training tools to permit units to exercise their battle staffs on a regular basis.
- Tables of organization and equipment for battalion and above should include a requirement for one or more mission command DMGs. As noted, DMGs are CPOF and digital mission command systems integration specialists. These specialists provide on-demand informal training for peers and are always nearby to provide both system and systems integration consultation to less experienced members of the battle staff.

  The Army should create a new series of warrant officers (WOs) to provide skilled support to the mission command warfighting function. These "Command and Control System Operational Managers" would provide present and persistent expertise in the science of mission command from battalion up through the Army Service Component Command. These positions could be either additions to the S3/Operations and Plans (G3) staff, or a reclassification of a current billet in the S3 staff. The Operations WO would be the primary SME for establishing the processes and procedures for receiving, distributing, storing, displaying, archiving, maintaining, managing, deleting, purging, and correlating information regardless of whether that is done using digital or analog systems. This person also would provide the expertise to set up, initialize, manage, and integrate the various digital systems including programs of record, commercial software, SharePoint, Google Maps, and various collaboration tools.

  In addition to these technical functions, the Operations WO would be available to provide persistent over-the-shoulder training, mentoring, and advice to system operators and the battle staff. This person would also be responsible for coordination or setup of simulations and stimulations for collective training events. Furthermore, he or she could serve as a training-focused technical liaison between the unit and the Mission Training Complexes. The Operations WO's role could also include many of the tasks and responsibilities currently associated with KM and the KMO. Many of the other warfighting functions/components/branches have already addressed this staff issue with WOs. For example, there are 16 WOs at the 2/1 AD's brigade CP alone. Yet the mission command warfighting function has none. The addition of an Operations WO in battalion- and brigade-level CPs might also mitigate the impact of high rates of personnel turnover in key battle staff positions.

The latter 2 recommendations are directed at the problem of maintaining a consistent level of battle staff and supporting specialized expertise in units over time. During discussions of this topic with brigade and battalion staff members, they remarked that maintaining a consistent level of mission command expertise is a difficult challenge for the unit's leadership. Loss of a few key specialists often has a significant impact on the unit's performance capabilities—single points of personnel-related performance risk.

The key issue in training for more-effective network-enabled operations is the development of higher levels of expertise on the part of individual Soldiers, crews and teams, and leaders. Much of the technology on display during the NIEs is "skill-biased" in the sense that it requires high levels of developed skill for effective use. Expertise is a function of suitable formal training followed by extensive job-relevant experience over time. Part of the solution to developing higher levels of expertise certainly involves additional training time. Results across NIEs speak volumes to this observation. But new objectives for and approaches to individual and team training also will be required, particularly for critical high-skill areas such as mission command (cf., for example, Hoffman et al. 2014).

On the final day of NIE/AWA 16.1, ARL/HRED's HSI team paid a return visit to the 1 AD's TAC (tactical action center)—2/1 AD's parent unit. Team members were discussing issues pertaining to mission command complexity, cognitive load, and network complexity with the TAC battle staff. The division's deputy commanding general (DCG) joined this conversation. After some discussion, he asked the team members to accompany him to his command vehicle (a point of presence, or PoP) where he proceeded to critique the vehicle and discuss aspects of Mission Command on the Move, as he had experience during NIE/AWA 16.1. The DCG was generally critical of the command vehicle's interior layout and ergonomic features. These HSI HFE deficiencies can and should be addressed. They are a driver of unnecessary complexity and extraneous cognitive load. However, near the end of the discussion, he paused briefly and noted that in spite of all the technology and capabilities available in his command vehicle, "Something is missing". He paused again and said, "Maybe it's training". The team's later judgment was that the DCG included himself in his remark about training.

HSI team members have heard this same comment expressed in different ways during prior NIE interviews and postexercise focus groups sessions. Some of the DCG's comments probably reflect the decidedly equipment- and technology-centric focus of the NIEs and much of Army acquisition in general. HSI support team members also have encountered an unspoken belief on the part of some unit personnel that the new digital technologies used in mission command will "do their jobs for them". Consequently, less training and experience on their part are necessary. Experienced commanders and other observers have warned repeatedly against placing the emphasis for mission command and other aspects of network-enabled operations on the "gizmos rather than on the people using the gizmos" (Wallace 2005, p. 20). Personnel, training, and organization are important aspects of overall mission command system performance. Wallace (2014, p. 1) further emphasized that "All who have a hand in the network need to understand its capabilities, its vulnerabilities, and be trained in its use". The issue of staff- and command-level training for mission command system and network users is addressed in greater detail in Section 3. That topic was a fallout of the team's initial consideration of the impact of network complexity on mission command operations.

3. Analysis Results, Part B: Initial Observations on Network Complexity

As noted previously, the HSI support team's charter for NIE/AWA 16.1 was expanded to include network and network operations complexity and the impact of that complexity on mission command performance. The team's extension into network-related issues was an exploratory effort intended to set the stage for a more detailed assessment of these topics in subsequent NIEs. Explicit findings and recommendations as such are not provided; that would be premature at this stage of the team's assessment. The following remarks are cast solely in terms of initial observations and related discussion.

Prior to discussing NIE/AWA 16.1 observations, 2 background topics must be introduced. First, it is essential to bear in mind that the network, or network "backbone" as it is sometimes called, is an essential prerequisite for network-enabled operations. Without the supporting network, the individual mission command systems such as CPOF attached to that network are of limited utility. Second, since the current topic is network complexity, it is necessary to define the term complexity, or the state of being complex. At a basic level, the number of parts and the ways in which they interact characterize the complexity of a given system. TRADOC Pamphlet 525-5-500 (Headquarters 2008) defines 2 components of complexity: structural and interactive. Structural complexity is based on the number of parts in a system. The larger the number of independent parts in a system, the greater its structural complexity. Interactive complexity is based on the behavior of the parts and the resulting interactions among them. The greater the freedom of action of each individual part and the more linkages among the components, the greater the system's interactive complexity.

3.1 Observations

3.1.1 Observation 1

The deployment of WIN-T Increment 2 involved a significant increase in complexity over and above WIN-T Increment 1 (i.e., the Joint Network Node [JNN]).

3.1.2 Discussion

WIN-T Increment 1 involved 8 network nodes, 2 at the brigade level and 6 at the battalion level. WIN-T Increment 2 involves a minimum of 58 items of communications equipment for an Infantry BCT. Using the basic definition of complexity provided in Section 3, WIN-T Increment 2 is obviously considerably more complex than its predecessor JNN. There is more structural complexity—a greater number of components—and these components interact extensively.

The substantive issue here is not complexity per se but rather whether this increase in network complexity is "puzzlingly complex" to users. Just because something is complex does not necessarily mean that it is puzzlingly complex provided that users have been properly prepared for its use and support (Norman 2011). Puzzling complexity is in the eye of the beholder. Perceptions of complexity are moderated by an underlying logic in physical design and conditions of use that once mastered are no longer perceived as complex. It is true that WIN-T Increment 2 is more complex than its predecessor when judged by the metrics cited in the provided definition. However, user comments about network complexity encountered during the NIEs must be interpreted cautiously. For certain, there are ergonomic problems (design features and usage procedures) with various items of network equipment. Results from across 7 NIEs also suggest that many network users have not been properly "trained in its use", as Wallace (2014) broadly defines that phrase. It is also arguable that many of the network-related problems attributed to complexity actually reflect the Army's failure to adequately manage complexity during the system's initial introduction to tactical units. Norman (2011) asserts that managing complexity is a partnership between equipment developers and users. Designers have to produce systems that "tame" complexity. But users have to take the time to learn the structure of their new tools and practice the skills involved in their effective use. In the case of CPs as observed across NIEs, neither of these aspects of managing complexity has been done particularly well.

3.1.3 Observation 2

For the first time in the Army's history, substantial communications and network capabilities have been placed in the hands of non-Signal Soldiers. Important network usage considerations such as bandwidth awareness, cyber security, information security, password protection, the risks associated with third-party software, and so forth, are in the hands of non-Signal users rather than Signal communications specialists (Wallace 2014).

3.1.4 Discussion

Historically, the Signal community never understood or cared much about the mission command applications attached to the network other than making sure there was a network robust enough to handle the bandwidth requirements of mission command systems. Signal troops set up and managed the network and users "plugged in" their mission command applications. Now, Capability Set fielding includes fielding a network but not necessarily fielding it to Signal Soldiers for installation, operation, and maintenance. The majority of WIN-T Increment 2 items are fielded to the operational side of the user community. Signal responsibility is limited to configuring and managing the network; operating the network to support mission command is the responsibility of general purpose users with minimal Signal Soldier support. The effect of this shift in concept is yet to be fully understood but its implications are clear: All who interact with the network need to understand its capabilities and be appropriately trained in its use (Wallace 2014). The "all" in the previous sentence includes both the battle staff and Signal troops in the unit's S6 shop. Wallace further remarks that this represents a significant and as of yet not fully defined training challenge.

3.1.5 Observation 3

Mission command and network responsibilities are blurred under the Capability Set concept. When mission command systems are attached to the WIN-T network, they become part of "the network". Mission command system problems such as those affecting interoperability become interpreted by users as a network problem. The distinction between what is the network and what is mission command application is not always clear.

3.1.6 Discussion

Under Capability Set fielding, mission command applications are so tightly integrated into the network (via the user's mission command platforms) that Signal troops are now inextricably and unavoidably involved in mission command. Similarly, mission command users are unavoidably involved in network operations. Mission command applications are hosted, interfaces are developed, and all are tested as an integral part of the WIN-T system. This represents a fundamental shift in the way Signal troops and the Army field a network. Things are no longer as simple as plugging in to a network maintained by a somewhat independent entity. New forms of understanding and interaction on the part of Signal support personnel and network users are required.

3.1.7 Observation 4

Signal Soldiers in unit S6 shops are nearly universal in their opinion that the training provided by the Signal school, along with the current structure of Signal military occupational specialties (MOSs), is not adequate to support current materiel and operational concepts for network-enabled operations.

3.1.8 Discussion

As noted, Signal Soldiers in unit S6 shops (officers and enlisted) do not think the training they received in the Signal school was adequate for them to support network-enabled operations as encountered during the NIEs. There is a skills gap between what Signal Soldiers bring with them from Advanced Individual Training and what job performance in a unit setting now requires. S6 personnel offer up 3 general reasons for inadequate institutional training: 1) lack of a hands-on focus during institutional training, 2) lack of training on the equipment they will actually use when assigned to a Capability Set–equipped unit, and 3) the MOS-focused (stove-piped) structure of institutional training does not match the skill structure of the contemporary S6 work environment. With respect to the latter, S6 officer cadre report that contemporary network-enabled operations require a more broadly and deeply trained Signal Soldier than was the case in the past. Many of the job-related competencies now required of Signal troops cross current MOS boundaries. Additional intra-MOS training (skill deepening) along with cross-MOS training (skill broadening) is required when Soldiers report to a unit. Units are often unable to provide the necessary training.

One result of these training deficiencies and MOS-job structure mismatches is an excessive reliance on experienced Signal troops (senior NCOs and WOs) and FSRs to support S6 operations during the NIEs. FSRs "fill in" the high-skill gaps that Signal Soldiers are not able to cover. This observation is supported by results reported in the RAND Corporation's Signal Soldier Workload Analysis performed during NIE 12.1 (Gonzales et al. 2012). The personnel issue in S6 shops, considered alone at least, might not be so much manpower and workload-related (too few personnel) as it is skill-level and skill-breath related (inadequately prepared personnel). One final and encouraging comment in this regard is that FSRs and experienced Signal troops do not regard the network backbone (i.e., WIN-T), unencumbered by attached mission command applications, as excessively complex—that is, puzzlingly complex. This view supports results reported in Analysis Part A that what is not familiar often is perceived as complex and intimidating. Familiarity gained through training and on-the-job use moderates perceptions of complexity. However, this observation must be viewed with caution. FSRs "back up" Signal troops in many ways that may not be fully apparent even to experienced S6 personnel. It is uncertain that current concepts for network-enabled operations could be sustained in the absence of extensive FSR support. Additional analysis of S6 skill and experience requirements to support network-enabled operations is necessary.

3.1.9 Observation 5

Wallace (2014) insightfully remarks that the contemporary network can be "maneuvered," not in the traditional sense of unit maneuver but in the sense that the "pipes" over which the information flows can be technically adjusted to the needs of the mission. He further comments that this maneuverability demands awareness, training, and a degree of network-related technical understanding on the part of commanders and key staff officers. Authority and responsibility cannot be left in the hands of Signal specialists absent clear direction and understanding of the commander's intent. Commanders and their supporting staffs must learn to "command the network" much as they would any other critical and limited resource. Similarly, S6 personnel must learn to coordinate with the battle staff to "maneuver the network" in accordance with the unit's scheme of maneuver. Suitable training and on-the-job practice on the part of both parties is required.

3.1.10 Discussion

Wallace (2014) emphasizes that one of the most frequently cited concerns about "the network" is lack of training in its use. The previous discussion of NIE findings and recommendations has addressed various aspects of training related to the technical and operational use of the network as well the mission command systems attached to it. What has not been addressed in this previous discussion is training focused on commanding the network or maneuvering the network in accord with the commander's intent as Wallace uses those terms. The former is primarily the commander's responsibility, while the latter is the responsibility of leadership in the S6 shop. These 2 groups must learn to work together to achieve a common end in ways they have not had to do in the past.

ARL/HRED's HSI team witnessed aspects of this interaction during observations of mission command operations during NIE/AWA 16.1. However, it is not clear that what is required in this respect (i.e., concepts, knowledge, skills, and competencies on the part of both groups) has been fleshed out to the extent that suitable training could be developed. Wallace further remarks (2014, p. 2) that the speed at which the network has evolved "has eluded contemporary organizational and institutional training solutions". The Army's formal training institutions typically are slow to respond to rapid evolutionary change. Moreover, most tactical organizations are not fully aware that such change is happening or are not in a position to develop or deliver essential training. Additional exploration, clarification, and operational definition of Wallace's concepts of commanding and maneuvering the network clearly is necessary. A deeper review directed at this issue beginning with NIE 16.2 could provide part of the basis for clarifying the nature of training and follow-on skill development now required in this respect.

In the aforementioned case study of the evolution of network-enabled operations in early Stryker brigades, Gonzales et al. (2005) provide results that support the observation in the previous paragraph. These authors noted that tactical SOPs in the first few Stryker brigades emphasized the importance of training Soldiers and leaders to operate on the network. They went on to remark that achieving an appropriate level of understanding required leaders who were "well-versed in all aspects of Stryker brigade doctrine, the network-enabled operational concepts contained therein, and in the capabilities and limitations of the networking and battle command systems of the Stryker brigade" (p. 37). It should also be noted that the network used at that time (circa 2005) was considerably less complex than the network observed during the NIEs.

3.1.11 Observation 6

Paper maps and other analog products remain present in NIE CPs. This observation does not directly pertain to network complexity but it might be significant with respect to effective mission command in the future. The HSI support team has observed the "creeping addition" of analog products into CPs over the course of 7 NIEs. The primary reason given for maintaining a paper map and other analog products is as a back-up for digital systems. However, observations in CPs across NIEs have indicated that paper maps are the primary tool used by battle staff personnel to collaborate and plan operations. Soldiers note that paper maps allow them to step back to see the "big picture", then step forward to see the details of the terrain while maintaining the context of the big picture through their peripheral vision. This capability does not appear to be as readily enabled with the current level of digital display technology in CPs. One possible reason for the persistence of paper maps as the "go-to" option for the battle staff is that paper maps have evolved over time to present only key and essential information to viewers. With minimal training and little experience, battle staff members using a paper map can rapidly gain the context of the terrain, both in detail and in an expansive view.

3.1.12 Discussion

During a discussion of mission command complexity and cognitive load, a former BMC commanding general (CG) digressed at length on the issue of paper maps and the analog "wing board" versus current digital displays in NIE CPs. The CG quipped that he could stand in front of a properly laid out wing board and get the gist of the tactical situation in less than 30 s. He went on to note that he could not do that as readily with current digital displays in CPs. HSI team observations of CP operations across NIEs along with the creeping addition of analog displays lead to a number of questions related to the CG's remarks. Is there something about a highly evolved analog tool such as a wing board that assists commanders in performing mission command that is more difficult to achieve with current digital displays? Does a wing board facilitate "cognitive fusion" of essential information in ways that are more difficult to achieve using contemporary digital displays? Admittedly, there is more terrain detail on a paper map than is apparently provided on current digital maps. Does what HSI team members have observed in NIE CPs reflect something intrinsically limiting about digital display technology or simply reflect the limits or poor design of current digital displays? Klein (1997) argues that an excessive focus on decision support technologies coupled with too little consideration of the actual cognitive mechanisms underlying expert decision making can reduce rather than improve decision-makers' performance. He asserts that improperly structured information technologies can interfere with the expression of expertise on the part of skilled commanders and staff members.

Further, is what the team has observed a training and experience-related phenomenon? Does the observed reversion to analog products in NIE CPs over time reflect commander and staff lack of experience with digital mission command systems, as discussed at length in Analysis Part A? Are these personnel simply accustomed to doing things "the old way" and have not yet adapted their command style and staff practices to a digital mission command setting? In this respect, Gonzales et al. (2005) reported that in the absence of adequate training and follow-on practice, commanders and supporting staffs in early Stryker brigades abandoned network-enabled systems and resorted to more familiar analog systems and methods. Should paper maps and digital displays be considered complementary? If so, in what sense should they be considered complementary? Is there an idiosyncratic aspect of being complementary? It is true that digital maps provide a common and rapidly updatable frame of reference across a unit's CPs that is difficult if not impossible to achieve using analog products such as a paper map. It is also true that analog tools provide an ultimate backup for digital mission command systems in the event of their failure.

The fact that older display media such as paper maps are creeping back into NIE CPs might be telling us something. Perhaps that "something" is simply a lack of familiarity with new digital technologies on the part of commanders and their supporting staffs. But, it may also reflect something deeper that might be essential to aspects of effective mission command, as Klein's extensive body of work on decision making might suggest. (cf. Klein 2009).

4. Perspectives on HSI at the System-of-Systems and Unit Levels

As noted previously, Army HSI efforts have traditionally been applied at the individual system level for programs of record, and that has been the case with most of the individual mission command systems such as CPOF comprising NIE CPs. What has not been adequately addressed is the evaluation of HSI issues arising out of the relationships between Soldiers and technology, not just at the individual system level but also at the system-of-systems and organizational levels. Some of the most demanding and problematic aspects of mission command operations as observed across NIEs are emergent issues that only show up when the individual systems comprising the CP are brought together, configured in a particular way, and placed in a unit context. These emergent performance issues might not show up in an isolated assessment of individual mission command component systems. For example, a majority of the contributors to mission command complexity and extraneous cognitive load discussed in Analysis Part A (e.g., component interoperability, operational integration, KM deficiencies, and battle staff team training) are emergent issues associated with cobbling the individual systems together to support mission command as an integrated warfighting function. It is arguable that the aggregate performance effect of these emergent issues exceeds that associated with design features and training for the individual mission command systems considered in isolation. Yet the focus of most HSI assessments is on individual mission command systems considered mostly in isolation.

HSI for a system of systems involves more than simply rolling up the assessments for the individual components while asserting that the resulting "composite" picture accurately reflects the whole (Vicente 2006; Walker et al. 2009). The performance effect of the whole is more than the sum of the effects of its parts. One lesson to be taken away from ARL/HRED's BMC support work is that HSI assessments for a system of systems such as a CP must reflect the integrated, team-based nature of the work performed in that job setting.

Beyond system-of-systems-level concerns, additional HSI issues are encountered when equipment suites such as a CP are embedded within their broader operational context. Functional systems of systems such as a CP composed of teams in interaction with a tool suite display cognitive properties that are radically different from the properties of those individuals acting alone (Hutchins 1995). What is necessary in these cases is an assessment of naturally situated cognition in which the unit of cognitive analysis is work as it is performed by a functional team operating in its natural operational setting. For example, consider the performance issues discussed in Analysis Part B. The performance impacts associated with Wallace's (2014) notions of commanding and maneuvering the network are important with respect to a unit's mission command effectiveness. Yet these issues might not have surfaced in an assessment of individual mission command systems, the network (i.e., WIN-T), or even during a more holistic assessment of the CP considered out of its natural operational context. To observe the impact of these issues, it was necessary to place the CP in its unit context and interplay the interplay of the functional team consisting of the battle staff and S6 personnel while pursuing the unit's mission objectives.

Some observers might argue that operational testing provides a suitable setting for the study of naturally situated cognition. However, the limitations associated with formal operational testing often act to constrain Soldier and team performance in ways that make that setting somewhat unrepresentative of the natural environment. Most operational tests consist of a series of scripted events (Hawley 2007; Hawley and Mares 2009). Scripting has a tendency to reduce test player performance variation in response to operational cues during actual test runs. For example, a commander executing a preplanned mission may have very few decisions to make primarily because key decisions were made long before the operation was undertaken. Scripting is a limiting factor during the NIEs, particularly when the event is being used as a vehicle to support formal operational testing for programs of record. However, the more open and free-play environment associated with the NIEs tends to mitigate the effect of scripting even for systems undergoing formal operational tests. There is more opportunity for the full range of potential test player response variability in response to operational cues to break through test-imposed constraints.

Given the HSI issues cited, why is there so little emphasis on holistic system-of-systems-level assessments along with a deeper look at "cognition in the wild"

(Hutchins 1995)? The simple answer to this question goes back to the funding mechanisms for HSI assessments. Simply stated, HSI assessments are paid for by program managers (PMs) for programs of record. A CP consists of a collection of systems developed by individual PMs who pay for HSI assessments of their systems. The same is true when those systems are taken to formal operational tests. There is no PM for the CP considered as a system of systems. Consequently, a holistic HSI assessment of the CP considered as a system in and of itself is not performed. Taken together, system-of-systems-level analysis and a consideration of what might be termed cognition in the wild represent a new and important challenge and opportunity for HSI.

5. Conclusion

The ARL HSI support team's mission command complexity-cognitive load work during NIE/AWA 16.1 primarily focused on validating and refining findings and mitigation recommendations from previous NIEs. In addition, the team's charter for NIE/AWA 16.1 was expanded to include an initial look at network and network operations complexity and the effect of that complexity on mission command capabilities and performance. With respect to mission command complexity and associated cognitive load, the team validated and refined previous observations concerning the effect of 1) mission command component integration and interoperability, 2) operational integration (to include KM), and 3) individual and team training for battle staffs. Deficiencies in each of these areas combine and act to increase the aggregate level of perceived complexity and cognitive load for commanders, their supporting staffs, and individual system operators. The mission command role itself can be intrinsically complex and demanding. Considerable expertise is required of individual battle staff members and for the battle staff functioning as a team. This is particularly true in contemporary, information-rich CPs exercising network-enabled mission command. A work setting with a large number of design-related "rough edges" will give the impression of being more complex and intimidating than one that has been better designed and integrated for effective use. Poorly designed and integrated work settings have been demonstrated to require higher levels of individual and team expertise to maintain effective performance. Battle staff teams have to compensate for materiel and interoperability-related inadequacies, and this becomes a major driver of cognitive load. To be certain, some aspects of the cognitive load associated with mission command in NIE CPs are intrinsic to battle staff roles. But high levels of extraneous cognitive load often are needless consequences of insufficient attention to HSI in mission command system design and integration coupled with inadequate training for individual system users and battle staffs operating as a team.

The HSI support team's introductory assessment of network and network operations complexity resulted in a number of observations that will be explored in greater detail during subsequent NIEs. The most significant of these results stem from the observation that network-enabled operations tend to blur the distinction between mission command and network operations. This blurring of roles will lead to a requirements for a unit's battle staff to better understand how to command the network and for S6 personnel to better understand how to maneuver the network to support the unit's scheme of maneuver. As Wallace (2014) emphasized, all who come into contact with the network must be trained in its use and understand its capabilities and limitations. The concepts, knowledge, skills, and competencies in each of these areas have yet to be fully described.

The findings and recommendations discussed in Analysis Part A are important with respect to mitigating the extraneous cognitive load associated with network-enabled mission command in NIE CPs. However, the list of mitigations discussed herein is not exhaustive. Undoubtedly, there are a number of additional interventions that also could be used to enhance mission command effectiveness in contemporary CPs. Several of these interventions are currently being explored as part of the Army's ongoing Human Dimension initiative.

ARL/HRED's HSI support team has also observed that NIE CPs are very "noisy" places, where noise is defined as excessive mission command performance variation, both within and across CPs, attributable to new and sometimes untried equipment suites along with unrefined and not fully implemented DOTLP products. As noted, these sources of uncontrolled variation also lead to excessive cognitive load in mission command operations. It is also arguable that the contributors to excessive process variation discussed in this report dominate the mission command performance situation. That is, failure to control these unnecessary sources of variation creates so much noise in the overall mission command process that the effect of other less dominant, but potentially important mitigations might get lost in the noise, so to speak. The "signal" associated with these less dominant contributors to mission command effectiveness cannot be separated from the overall noise level in the CP. Bringing mission command processes under control requires that the signal-to-noise ratio in CPs be reduced by first addressing the performance variation attributable to the dominant contributors identified in this report. That will open the door for a consideration of other factors potentially affecting mission command performance. Box and Draper (1998) refer to the progressive dampening of the signal-to-noise ratio in a new process as "cutting the grass", which involves identifying and eliminating obvious contributors to extraneous variation in a process so that important but less-dominant contributors can be identified and remedied. Until the grass is cut, these lesser sources of variation may not stand out enough to be identified and remedied. Box and Draper (1998) assert that progressively cutting the grass is an important aspect of bringing a new or modified process under control. In this usage the new process is network-enabled mission command.

Stepping back and taking a broader view of force modernization and looking beyond the specifics of the results presented in this report, it is arguable that many of the factors contributing to mission command complexity and extraneous cognitive load in NIE CPs stem from a failure to manage complexity during the design, development, and fielding of new mission command equipment suites. As noted, Norman (2011) asserts that managing complexity involves aspects of both system design (broadly defined herein to include the CP as a work system) and adequate preparation of users to employ those new systems. It is also arguable that failure to manage complexity is an artifact of 3 "sins" associated with the way the Army approaches the development of new systems and technologies. These sins are characterized as follows:

1) *An excessive preoccupation with equipment (hardware and software) during concept development, system design, materiel development, and operational testing*. Sociotechnical aspects of system development, testing, and effective use typically are given less emphasis and are generally not considered until the system is near fielding. Much of this preoccupation with materiel is driven by funding considerations (cf. Coakley 1991). That said, it is difficult to manage complexity from the point of view of users after a system is nearly fully developed and users must be fit to that system after the fact. Many degrees of freedom are lost as the system becomes more fully developed. In their assessment of network-enabled operations in early Stryker brigades, Gonzales et al. (2005) concluded that a robust DOTLP package is essential to achieving the full potential of new technical capabilities. They went on to assert that "sometimes, it is the non-materiel aspects of the unit's Mission Capabilities Package that are the most important" (p. xiv).

2) *Lack of an overarching system-of-systems focus for team-based work systems such as a CP*. The ARL team observed and reported that many of the issues driving complexity and extraneous cognitive load in NIE CPs result from the fact that CPs are cobbled together from components developed by individual proponents and vendors. In many cases, these components are developed and evaluated in isolation with little consideration given to how they "fit together" to support mission command as integrated cognitive work. It is left to the battle staff to knit these components together to support mission command as an integrated

warfighting function. In the case of CPs as observed during the NIEs, this "knitting together" process often results in extraneous cognitive load and can impose demands that cannot be overcome by the unit's organization, people, or available training resources (Command Post 2025 2014).

Norman and Kuras (2006) argue that an important aspect of systems engineering for complex systems of systems such as a CP is identifying and then resolving or reducing the pressures that impede knitting together the process described in the first paragraph of no. 2. These authors also caution that mitigating such pressures is not a "one-time-and-done" action. Different equipment configurations, new mission types, new doctrinal concepts, and the like will interact to produce new sources of pressures on users. This is the essence of the emergence phenomenon observed with systems of systems such as a CP. In short, there will always be a requirement for expert, flexible, and adaptive battle staff personnel. Improvements in technology will not eliminate this requirement.

3) *Failure to consider organizational learning processes during the period leading up to system evaluation*. The issue of organizational learning is important with respect to how well a test unit will use new equipment suites during an exercise such as the NIEs (Alberts and Hayes 2002). It is unrealistic to expect that complex new equipment suites can be "dumped into" an organization without having an effect, often detrimental initially, on how well that organization performs its intended missions. As stated several times herein, new technology often changes the nature of the work that technology is intended to support. A receiving unit must adapt to this new technology and learn how to use it effectively. This adaptation process takes time and requires more than traditional new equipment training (NET). Traditional NET assumes that the receiving organization will use new systems or technology in much the same fashion that it used older equipment. The tacit assumption is that not much adaptation or organizational learning is necessary. To the extent that is not true and new organizational forms, processes, and procedures are required, traditional NET will be inadequate.

The result of any significant change in systems and technology will be a unit performance trace similar to that shown notionally in Fig. 1. The introduction of new equipment suites at point A typically results in an initial fall-off in unit performance. The period between points A and B characterizes the time during which the unit is learning to use new equipment effectively—an operational integration period. The availability of supporting products such as those recommended in Analysis Part A can shorten the duration of the adaptation and learning period and lessen the depth of the performance drop-off. But there will still be a performance drop-off as the unit adapts to new materiel and develops and implements new processes and procedures. After notional point B, unit performance should rise above the preintervention performance level, and the effect of the new technology can be assessed.

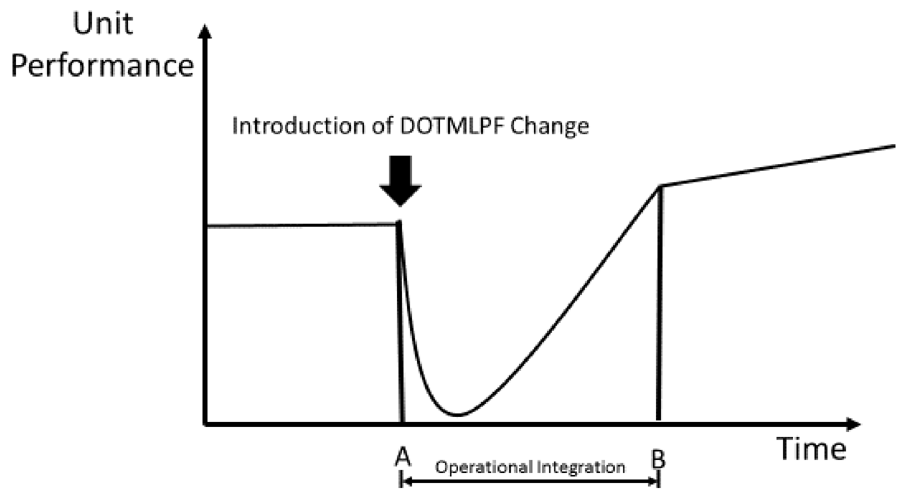

Fig. 1 The disruptive effect of new systems and technologies on unit performance

Multiple and concurrent equipment changes can have a cumulative and possibly nonadditive impact on unit performance (i.e., 1 + 1 > 2). That is, multiple equipment changes requiring corresponding DOTLP changes will increase the complexity of the unit's learning and adaptation processes and increase the length of the adaptation period and possibly deepen the performance drop-off. This situation is illustrated notionally in Fig. 2. Change is disruptive, and multiple changes are cumulatively disruptive.

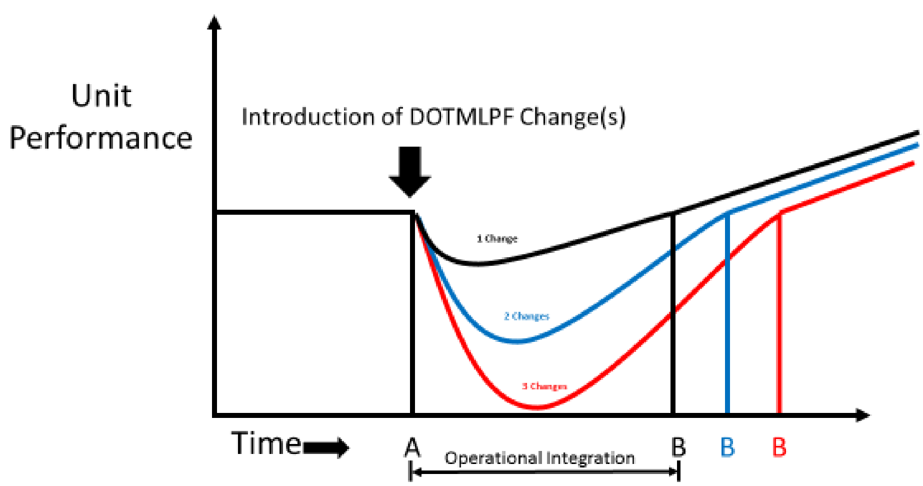

Fig. 2 The cumulative effect of multiple new systems and technologies on unit performance

The problem with system assessments during the NIEs and much of Army testing in general is that units generally are not given sufficient time for organizational learning and adaptation to take place. In general, pre-event training is driven by time and schedule considerations rather than the level of performance resulting from experiencing that training. Results from across multiple NIEs strongly support this observation. As a consequence, performance assessments often are carried out during the “trough” between points A and B. The result can be misjudgments concerning the potential military utility of new systems and technology as well as the DOTLP package required to adequately support them. Alberts and Hayes (2002) stress that performance rather that time or funding should determine when an individual or unit is ready to proceed with formal testing.

These issues affecting successful force modernization are not new. Binkin (1986) and Demchak (1991) discuss at length the Army’s experiences during the “great wave” of force modernization during the late 1970s and 1980s. For the Army, this was the period during which the “Big 5” (Abrams Main Battle Tank, Bradley Fighting Vehicle, Apache Attack Helicopter, Black Hawk Helicopter, and Patriot Air Defense System) were introduced into the force. Many of the receiving units’ initial experiences with these systems were not positive. Modernization often did not proceed smoothly. A number of the observed problems resulted from the fact that system developers failed to consider the “information load” these systems would impose on receiving units and the organizational, procedural, and training impacts that would result (Demchak 1991). Often, the effect of that performance load was underestimated, downplayed, or simply not known in advance.

It is arguable that the lessons of this earlier work on force modernization are still relevant today. In fact, those lessons may be even more relevant today given the shift in types of modernizing technologies between that period and the present. Modernization during the 1970s and 1980s primarily involved electro-mechanical technologies. The use and effects of information and communication technologies (ICTs) was considerably less than today. Contemporary modernization initiatives such as those observed in NIE CPs primarily involve ICTs. Levy and Murnane (2012) argue that the increasing use of ICTs in the workplace fundamentally changes the nature of work and the skill, knowledge, and experience requirements of the people who perform that work. ICT-dominated work is more cognitive and conceptual in nature. It might be said that ICTs are doubly skill-biased in the sense that they require higher levels of mental ability as well as higher levels of education, training, and experience for effective use. In short, ICT insertions such as those observed during the NIEs heavily affect the unit’s organizational structure, personnel needs, and skill requirements. To reinforce this point, Gonzales et al. (2005) observed that the initial organizational structure of Stryker brigades had to be changed to better take advantage of their new digital systems. The organizational structure of Stryker brigades was redesigned around the new network-centric operational concept.

As emphasized in this report, successful force modernization involves far more than simply giving a unit new equipment and assuming that Soldiers somehow will make it work. It is arguable that with the complex equipment suites used to support network-enabled operations, DOTLP adaptations are at least on a par with materiel as contributors to increased force effectiveness. In an award-winning paper, Fischerkiller et al. (2002) support this argument, remarking that "if the services modernize at the expense of skill accounts, they may be unable to exploit new technology to its fullest. Even worse, it may be that mistakes by information-overloaded, undertrained troops expose even radically modernized forces to sudden heavy losses on a very lethal 21st century battlefield" (p. 39). To take full advantage of the opportunities provided by new technologies, a broader and more balanced approach to force modernization and unit adaptation to new technologies is necessary. The innate complexity associated with the introduction of these new technologies must be proactively managed.

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List of Symbols, Abbreviations, and Acronyms

2/1 AD	2nd Brigade Combat Team, 1st Armored Division
ARL	US Army Research Laboratory
AWA	US Army Warfighting Assessment
BCT	brigade combat team
BMC	Brigade Modernization Command
CG	commanding general
CLT	Cognitive Load Theory
COE	Common Operating Environment
CP	command post
CPCE	Command Post Computing Environment
DA	US Department of the Army
DCG	deputy commanding general
DMG	Digital Master Gunner
DOTLP	doctrine, organization, training, leadership and education, and personnel
FSR	field service representative
G3	operations and plans section
HFE	Human Factors Engineering
HRED	Human Research and Engineering Directorate
HSI	Human-Systems Integration
JNN	Joint Network Node
KM	Knowledge Management
KMO	knowledge management officer
MCCoE	Mission Command Center of Excellence
MCMD	Military Decision Making Process
MOS	military occupational specialty

NCO	noncommissioned officer
NET	new equipment training
NIE	Network Integration Evaluation
PM	program manager
PoP	point of presence
S3	Operations section
S6	Signal/Communications section
SME	subject matter expert
SOP	standard operating procedure
TAC	tactical action center
TRADOC	Training and Doctrine Command
WIN-T	Warfighter Information Network–Tactical
WO	warrant officer

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